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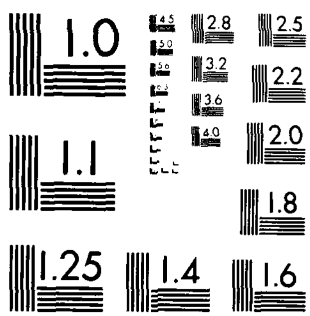

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OBJECTIVE QUALITY CONTROL OF ARTILLERY COMPUTER METEOROLOGICAL MESSAGES

APRIL 1980

By

ERNEST B. STENMARK

US Army Electronics Research and Development Command
ATMOSPHERIC SCIENCES LABORATORY
White Sands Missile Range, NM 88002

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Artillery computer meteorological (CM) messages are susceptible to having errors introduced into them (1) during preparation at the Meteorological Section, (2) during transmission to the user unit, and (3) during entry into the Fire Direction Center computer. Quality control during preparation of the CM message is largely a manual function and thus subject to human error. At the Fire Direction Center, in the case of the most advanced computerized tactical fire direction control system, TACFIRE, quality control of the CM message is limited to superficial automated checks that relate primarily to message

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format, not content, and to reliance upon visual screening by the TACFIRE operator before acceptance, storage, and usage of the message. No quality control checks of the contents of the message are made during movement of the CM message from the preparer to the user.

This report documents the development of procedures for objectively performing meteorologically consistent quality control checks on the contents of single CM messages that would require only very limited automatic data processing resources to implement at either the preparer or user end, or both, and that would improve upon the validity checks currently implemented in the TACFIRE system.

SUMMARY

Objective quality control procedures have been developed that are specifically applicable to the artillery computer meteorological message. The procedures are based upon a combination of physical principles and meteorologically consistent empirical relationships. The empirical relationships involved have undergone revision and refinement through examination and study of over 3200 upper air soundings from three different geographic and climatic regions.

Validity of the procedures has been demonstrated by the high percentage of errors detected in messages containing known transpositions of numbers and by successful detection of verifiable errors in independent sets of data from field sources.

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INTRODUCTION

One of the principal responsibilities of the Field Artillery Ballistic Meteorological Section is to provide computer meteorological (CM) messages to field artillery Fire Direction Centers (FDC) equipped with the Tactical Fire Direction System (TACFIRE), an integrated system of tactical automated data processing (ADP) and communications which replaces the field artillery digital automatic computer, gun direction, M-18, commonly referred to as the FADAC[1] and the manual/FADAC techniques of operation and fire direction at the battalion and division levels.[2]

The CM message provides the following essential meteorological inputs to the battalion ballistic trajectory computations: wind direction in tens of mils, wind speed in knots, virtual temperature in tenths of degrees kelvin, and pressure in millibars. These data are given for the surface and for each of up to 26 standard computer zones above the surface reaching to a maximum altitude of 20,000 meters above surface as required by the operational situation.

Accuracy of the meteorological data in the CM message as it is employed in the ballistic trajectory computations is vitally important. Unfortunately, CM messages are susceptible to having errors introduced into them (1) during preparation at the Meteorological Section, (2) during transmission to the user unit, and (3) during entry into the FDC computer. Quality control during preparation of the CM message is largely a manual function and thus subject to human error. At the FDC, in the case of the most advanced computerized tactical fire direction control system, TACFIRE, quality control of the CM message is limited to superficial automated checks that relate primarily to message format, not content, and to reliance upon visual screening by the TACFIRE operator before acceptance, storage, and usage of the message. The specific means of transmission of the CM message from preparer to user, whether by radio, voice, or messenger-carried punched paper tape determines whether or not errors may be introduced during the process, but in any case no quality control checks of the contents of the message are made during movement of the message.

This report documents the development of procedures for objectively performing meteorologically consistent quality control checks on the contents of single CM messages that would require only very limited ADP resources to implement at either the preparer or user end, or both, and

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[1]FM 6-15, Field Artillery Meteorology, Headquarters, Department of the Army, Washington, DC, 30 August 1978

[2]Reference Note: RN FC--AA, "TACFIRE, the Tactical Fire Direction System," US Army Field Artillery School, Office of the Deputy Assistant Commandant for Combat Developments, Fort Sill, Oklahoma, April 1975

that would improve upon the validity checks currently implemented in the TACFIRE system.

The body of this report discusses the limitations in the current procedures for maintaining quality control of CM messages and the development and testing of objective procedures for improved quality control checking on a single station, single message basis. Results obtained from applying the objective procedures to real data from different sources are presented as evidence of the validity of the procedures. Details of the calculations required to implement the procedures are given in an appendix.

DISCUSSION

It is possible for artillery CM messages as entered into the division TACFIRE system to contain data errors that may arise from various sources. The original atmospheric sounding data may be in error, or errors may occur in preparing the zoned data for the CM message format. Errors may also occur during transmission, delivery, or entry of the CM message into the TACFIRE system.*

Currently implemented objective procedures for checking the validity of data in the CM messages received by TACFIRE are stated[3] as follows:

> When a MET;CM message is entered, the message is validated and checked to insure that the time period of the message is not greater than 31 days and 23.9 hours. If greater, an error message is generated. In addition, the program also checks the met station's height and also performs a limit check on atmospheric pressure. The body of the MET;CM message is validated to insure that each of the line numbers are in the range of 00 to 26, and the wind direction is between zero and 640 tens of

*Tactical Database, TACFIRE reference note, December 1975, DT/OT III Edition, page 19, paragraph 10.B(2): "The program function, however, will not currently receive digital data directly from sources such as the Air Weather Service, or organic meteorological sections. Data are made available to TACFIRE operators via radio, voice or messenger, depending upon the tactical situation."

[3]DTM 11-7440-241-10, Chapter 7, DIVARTY Meteorological Function, Section 7-2.C., "Validation."

> mils. In addition, the wind speed should be between zero and 300 knots, the temperature between zero and 500.0 degrees, and the air pressure between zero and 1110 millibars.

Table 7-3, in the same reference, gives the allowable ranges for height of station in tens of meters as 0-999 and atmospheric pressure at station in millibars as 0-999.

These validity checks are effective in detecting a few major errors in message format, but are incapable of detecting many errors in message content that could easily result in incorrect ballistic solutions or even prevent the successful computation of any solution at all.

Current TACFIRE operating procedures require further that incoming CM messages be displayed and that operator action be required to accept and store the displayed message before it can be utilized. Presumably, bad data will be identified by visual examination of the displayed message; however, under the pressure of battlefield operational conditions, it appears unlikely that any corrective action will be taken for any message that has not been flagged by the system as having probable errors.

Ideally, quality control of computer meteorological messages would be accomplished by the originating activity to such an extent that any CM message received by the TACFIRE system could be accepted as containing correct and useful data as soon as routine TACFIRE validity checking had determined that the correct format had been received and that no transmission induced errors had occurred. The probability that errors will occur in the preparation of the CM message has recently been reduced to some extent with the fielding of the Meteorological Data Processing Group OL-192.[4] Errors are still possible though, since manual input of the raw meteorological data to the OL-192 is required. Eventually, with the advent of automated observing systems such as the Field Artillery Meteorological Acquisition System (FAMAS) and the direct digital communication links between the observing system and TACFIRE, the ideal may be realized. However, for the immediate future, CM messages containing significant data reduction and data entry or transmission errors may continue to be expected to enter the TACFIRE system.

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[4]Raymond Bellucci, Steven W. Burnett, and Thomas Richter, 1979, <u>Documentation of Software in the OL-192 Meteorological Data Reduction Program</u>, DELCS-TR-79-1, CS&TA Laboratory, Electronics Research and Development Command

Procedures similar to those discussed here were originally included in a set of computer software routines known as the "Proposed AMS-A for Corps TACFIRE (PACT)" system.[5] PACT was intended to fulfill the major meteorological processing functions required by a statement of work for the Corps field artillery section.[6] Quality control procedures introduced in the PACT system have been further refined and are described in detail here as general procedures for application to artillery CM messages. These procedures could possibly be incorporated into the field artillery system either at the point of origin of the CM message or at the point of application, or both. However it is accomplished, implementation of better objective quality control of CM messages can provide insurance against potentially large errors in meteorological corrections which might otherwise result in large inaccuracies in artillery fire and a consequent degradation of artillery effectiveness.

SINGLE-STATION, SINGLE-MESSAGE QUALITY CONTROL

Procedures described here are intended to apply to individual CM messages with no reference made to any past history of local meteorological conditions or to any current information relating to meteorological conditions in the surrounding area. These procedures are therefore equally applicable to the very first as well as the very last CM message ever to reach a given TACFIRE system.

The CM message is strictly formatted to provide for values of pressure, virtual temperature, wind direction and wind speed at the surface (line 00) and for each of 26 zones (lines 01-26) above the surface. The zone structure of the CM message is shown in table 1.[1] Column one of table 1 is the CM message line number corresponding to the meteorological zone for which the height value in column two defines the upper boundary. Column three gives the height value for the midpoint of the zone and column four gives the thickness of the atmospheric layer as measured between the midpoint of that zone and the midpoint of the next lower zone.

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[5] E. B. Stenmark, W. D. Ohmstede, D. R. Veazey, 1977, Proposed AMS-A for Corps TACFIRE (PACT) System Description, ASL Internal Report, White Sands Missile Range, NM

[6] Inclosure 1, "Software Requirement to Support Corps Field Artillery Section Using Division Artillery TACFIRE Hardware, Statement of Work," to letter, ATSF-CD-TD, USAFAS, 27 January 1977, subject: "TACFIRE Software Required to Support Corps Artillery Functions"

[1] FM 6-15, Field Artillery Meteorology, Headquarters, Department of the Army, Washington, DC, 30 August 1978

TABLE 1. ZONE STRUCTURE OF THE COMPUTER MET MESSAGE

Line No.	Top of Zone Height (m)	Zone Midpoint Height (m)	Midpoint-to-Midpoint Layer Thickness (m)
00	Surface	Surface	---
01	200	100	100
02	500	350	250
03	1000	750	400
04	1500	1250	500
05	2000	1750	500
06	2500	2250	500
07	3000	2750	500
08	3500	3250	500
09	4000	3750	500
10	4500	4250	500
11	5000	4750	500
12	6000	5500	750
13	7000	6500	1000
14	8000	7500	1000
15	9000	8500	1000
16	10000	9500	1000
17	11000	10500	1000
18	12000	11500	1000
19	13000	12500	1000
20	14000	13500	1000
21	15000	14500	1000
22	16000	15500	1000
23	17000	16500	1000
24	18000	17500	1000
25	19000	18500	1000
26	20000	19500	1000

Pressure and Temperature

The well-defined structure of the CM message permits objective testing of the vertical consistency of the pressure and temperature values based on accepted physical principles as they apply to the atmosphere. These principles are contained in a general expression known as the hypsometric formula which is based on the hydrostatic equation and relates the barometric pressure to height in the atmosphere, as governed by the existing conditions of pressure (P) and temperature and moisture combined in the virtual temperature (TV).[7]

The hypsometric formula can be written as

$$H_2 - H_1 = (R/G) * TVM * Log_e (P_1/P_2),$$

where

H_1 is height above sea level at the base of the layer in geopotential meters;

H_2 is height above sea level at the top of the layer in geopotential meters;

R is the gas constant for dry air (= 287.04 m/sec degrees kelvin);

G is a dimensional constant (= 9.8 m/sec per geopotential meter);[7]

TVM is the mean virtual temperature through the layer in degrees kelvin;

Log_e refers to natural or Naperian logarithms;

P_1 is the pressure at the bottom of the layer in millibars;

P_2 is the pressure at the top of the layer in millibars.

The value of the mean virtual temperature of the layer is approximated by the expression

$$TVM = (TV1 + TV2)/2.0,$$

[7]Manual of Barometry (WBAN), Appendix 7.1, Volume 1, First Edition, US Government Printing Office, Washington, DC, 1963

[7]Ibid., Appendix 8.0.1

where

TV1 is the virtual temperature at the bottom of the layer in degrees kelvin;

TV2 is the virtual temperature at the top of the layer in degrees kelvin.

The quantity $H_2 - H_1$ is thus the thickness of the layer in geopotential meters, which for all practical purposes can be considered to be geometric meters.

Line 00 (Surface) Pressure and Temperature. In normal meteorological practice, surface pressure and temperature for a given station would simply be checked against upper and lower limits for that particular site and elevation based on existing historical records for the station. Since the meteorological sites upon which the artillery depends cannot be expected to have any such historical records available, the procedure has been generalized to reducing reported surface values to sea level by using standard atmosphere relationships[1] and testing the reduced values against worldwide sea level extremes obtained from historical data.[8]

Lines 01-26 Pressure and Temperature. With the exception of the surface (line 00), all temperatures and pressures apply to zones of specified thickness (table 1) and are evaluated as the midpoint values of each zone. While line 01 refers to the zone from surface to 200 meters, the line 01 values of temperature and pressure are evaluated at 100 meters above the surface and can therefore be interpreted as being the upper boundary values of the 100-meter-thick layer having the surface pressure and temperature as lower boundary values. Similarly, line 02 pressure and temperature are the upper boundary values for the 250-meter-thick layer between the midpoints of computer zones 01 and 02, and so on through line 26 where the pressure and temperature are the upper boundary values for the 1000-meter layer between the midpoints of computer zones 25 and 26.

Reported pressure and temperature values can be checked at each line above the surface by using the hypsometric formula to obtain a computed thickness of each layer that has a given line value pressure and temperature as its upper boundary and then comparing this computed value

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[1] FM-6-15, Field Artillery Meteorology, Headquarters, Department of the Army, Washington, DC, 30 August 1978

[8] F. A. Berry, Jr., E. Bollay, and Norman R. Beers, 1945, Handbook of Meteorology, McGraw-Hill Book Company, Inc., First Edition

to the nominal thickness of that layer as given in table 1. A computed thickness value that differs significantly from the nominal is indicative of a probable error in either pressure or temperature.

Temperature - Vertical Structure. Computation of the thickness of a layer is much less sensitive to errors in temperature than to errors in pressure. It is therefore useful to perform an additional check on temperature values from line to line by considering the lapse rate over each layer. Serious errors of incorrect or transposed digits in temperatures may result in apparent superadiabatic lapse rate conditions in the vertical structure. For this application, these conditions are defined as lapse rates exceeding 1.2 degrees kelvin per 100 meters. Any such condition that is not continuous from the surface is rarely observed and in most cases results from erroneous data rather than real atmospheric conditions. Furthermore, any lapse rate immediately above the surface which equals or exceeds 3.5 degrees kelvin per 100 meters should likewise be flagged as a probable error in temperature, since such a rate would exist only in the condition characterized as "absolute instability," a transient condition found to exist only briefly over desert regions.[9]

Wind Speed and Wind Direction

The pressure and temperature checking procedures are readily recognized as being based on well-understood principles of the thermodynamic structure and behavior of the atmosphere. Factors governing the behavior of the atmosphere in terms of wind direction and wind speed relationships in the vertical are considerably more complex, less well understood, and much less amenable to straightforward analysis. However, within the meteorological community, the vertical wind structure has been subjected to extensive observation and study; and empirical relationships between wind speed and variability of wind speed and wind direction have been derived that permit relatively simple and useful testing of the reliability of wind values in any single message.

The rules and procedures discussed here have been adapted from an upper air verification program developed and used operationally by the Data Verification Section of the National Weather Records Center (NWRC).[10]

Allowable wind speed changes from one level or zone to the next can be expressed as a function of the wind speed at the lower level. In

[9] Horace Robert Byers, 1944, General Meteorology, McGraw-Hill Book Company, Inc., Second Edition, p 149

[10] "The Upper-Air Verification Program," 1970, Data Verification Section, National Weather Records Center, work paper compiled by the Upper-Air Unit (RAVU) under the direction of Wilson R. Tschiffely, Jr.

general, the higher the wind speed, the greater the possible change in wind speed in going to the next higher zone.

Allowable wind direction changes from one level or zone to the next can also be expressed as a function of the wind speed. In this case, generally the higher the wind speed, the less the wind direction is expected to vary from zone to zone.

Line 00 (Surface) Wind Speed. Wind speed at the surface is unlikely to exceed 60 knots except under hurricane or other severe weather conditions. Surface wind speeds outside the range of 0 to 60 knots should be considered likely to be in error.

Lines 01-26 Wind Speed. The critical values used by NWRC for determining possible wind speed errors are given in table 2 in whole knots for compatibility with TACFIRE usage. The data from this table are plotted as the straight-line segments representing wind speed intervals in the graph of wind speed versus change in wind speed at the next higher level (figure 1). To use a simple functional relationship for testing, a curve of the form

X = A + B * SQRT(Y)

has been derived, where X is the maximum wind speed change between zones, Y is the wind speed, A = 20, and B = 5.95. This function is represented by the smooth curve drawn in figure 1.

Limits to the curve are applied at X = 29, where any change in windspeed of less than 29 knots is accepted, and at Y greater than 95, such that wind speed changes are limited to no more than 78 knots for all wind speeds above 95 knots.

Any change in wind speed from one CM message line to the next that exceeds limits is interpreted to mean a probable error in the wind speed value at the upper line.

TABLE 2. WIND SPEED VERSUS WIND SPEED CHANGE

Speed at Lower Level (Knots)	Maximum Absolute Change in Speed Between Lower and Upper Level (Knots)
0-10	29
11-19	39
20-37	49
38-66	58
67-95	68
> 95	78

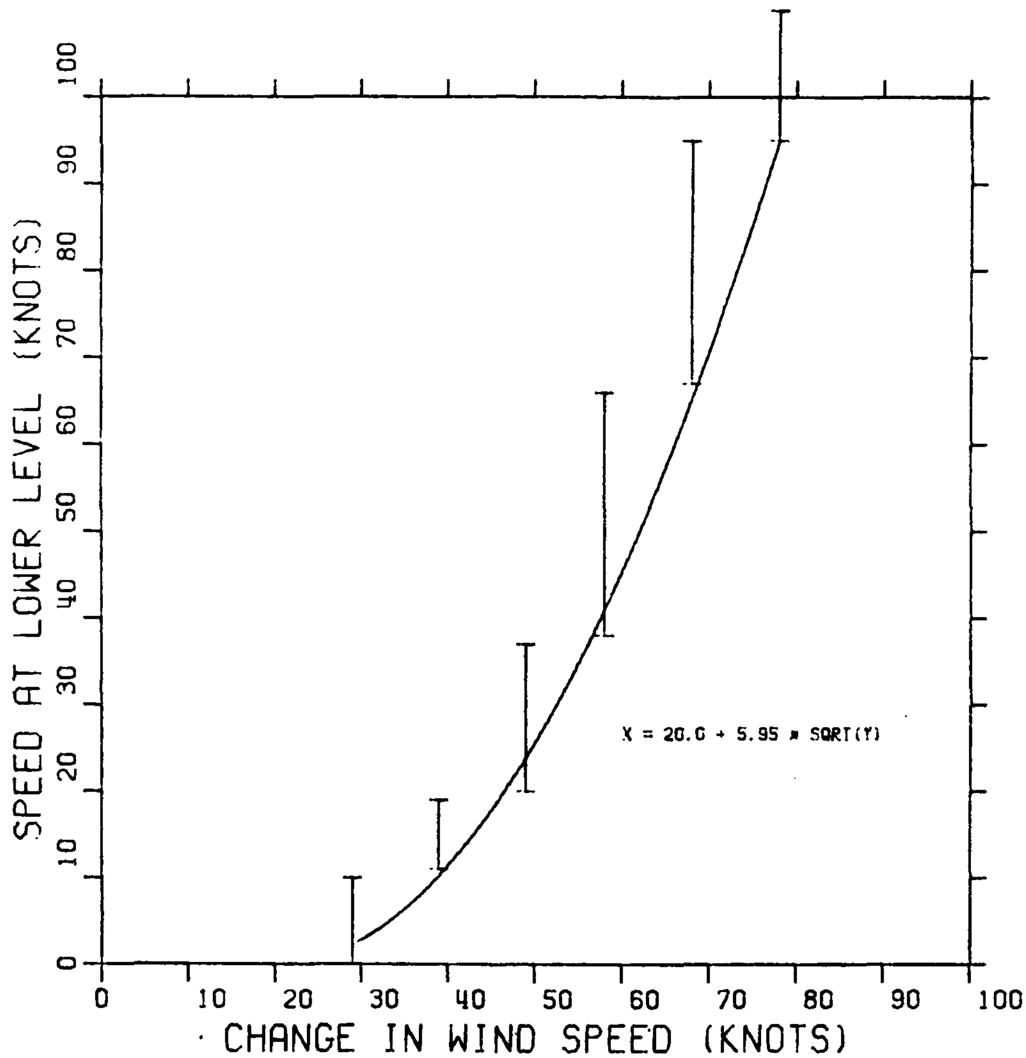

Figure 1. Wind speed versus change in wind speed.

Line 00 (Surface) Wind Direction. At the surface, any wind direction value between 0 and 640 tens of mils is accepted as valid; however, if the surface wind speed is 0, any wind direction other than 0 is considered to be an error.

Lines 01-26 Changes in Wind Direction. Critical values for determining possible wind direction errors between successive levels are given in tables 3 and 4 (in knots and tens of mils as required for TACFIRE usage). Following the procedures used by NWRC the values in table 3 apply when the pressure at the top of the layer being checked is greater than 150 millibars. Table 4 applies when the pressure is less than 150 millibars. In the CM message structure, the 150-millibar level generally exists between message lines 20 and 21. As adapted for this use, the table 3 values are used for upper level lines 01-20, and table 4 values are used for upper level lines 21-26.

The data from tables 3 and 4 are plotted in figure 2 as intervals of wind speed (knots) versus change in wind direction (tens of mils). Functional relationships have been derived for both sets of data with the form

$$X = A + B * Y,$$

where

X = allowable wind direction change (tens of mils);

Y = minimum wind speed (knots) occurring at the top or the bottom of the layer;

$B = -0.95$;

$A = 108.0$ for lines 01-20;

and

$A = 143.0$ for lines 21-26.

As in the case of wind speed versus change in wind speed, limits are applied to the functions for wind speed versus change in wind direction. In all cases, if the minimum wind speed is less than 25 knots, any change in direction is acceptable. If the minimum wind is greater than 76 knots, any wind direction change greater than 36 tens of mils is considered a probable error when the upper level wind is from lines 01-20, and any change greater than 71 tens of mils is considered a probable error when the upper level wind is from lines 21-26.

TABLE 3. WIND SPEED VERSUS WIND DIRECTION CHANGE
LINES 01-20

Lower of Two Wind Speeds (Bottom or Top of Layer) (knots)	Allowable Direction Change Between Bottom and Top of Layer (tens of mils)
0-19	Accept any change
20-37	89
38-56	71
57-76	53
> 76	36

TABLE 4. WIND SPEED VERSUS WIND DIRECTION CHANGE
LINES 21-26

Lower of Two Wind Speeds (Bottom or Top of Layer) (knots)	Allowable Direction Change Between Bottom and Top of Layer (tens of mils)
0-19	Accept any change
20-37	124
38-56	107
57-76	89
> 76	71

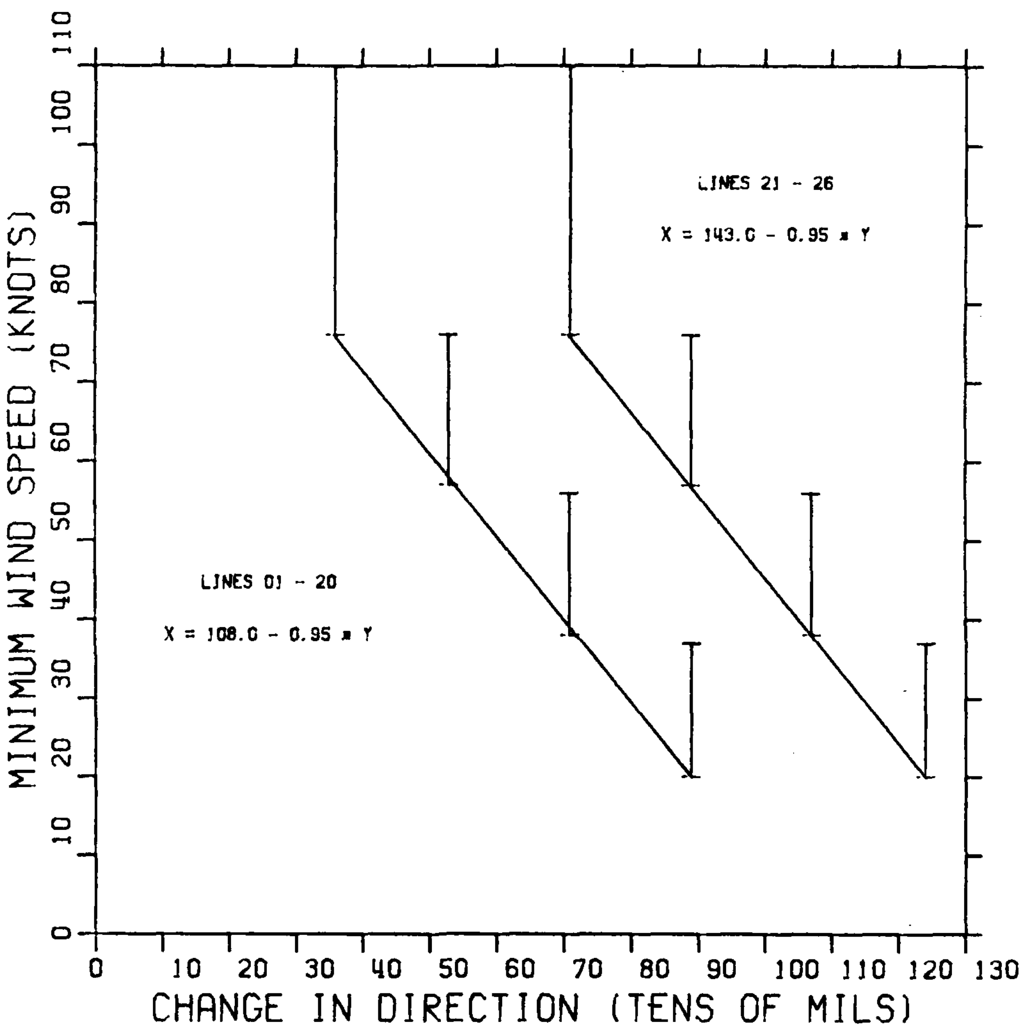

Figure 2. Wind speed versus change in wind direction.

DEVELOPMENTAL TESTING

Basic guidance for the development of the quality control procedures discussed here has been taken from an operational program of the NWRC.[10] Extensive testing was carried out against independently quality controlled upper air sounding data from different sources and climatic regions to assure that the procedures would neither unnecessarily flag insignificant errors, nor flag an excessive number of unusual but not necessarily incorrect data occurrences. As a result of this testing, considerable modifications were made to NWRC procedures and additional procedures were developed to address the particular problem of artillery CM messages.

Developmental Data

Developmental data sets for this purpose included the following:

a. 1552 soundings from 36 stations in Europe

b. 843 soundings from 25 stations in Northeastern United States

c. 831 soundings from 22 stations in Southwestern United States

CM messages were obtained from the data for each upper air sounding by computer processing. Since the input data had undergone extensive quality control, the resultant CM messages were considered to be virtually error free. Any apparent errors in these CM messages that were detected by the objective quality control procedures could thus be identified as unusual data occurrences rather than actual errors.

Development Results

Following full development of the objective quality control procedures for CM messages, testing of the total 3226 CM messages revealed that only 52 contained data unusual enough to cause probable-error flags to be set. Nearly all of the 52 probable-error flags resulted from large wind direction changes of the type that could cause significant errors in artillery fire if they were actually incorrect data.

VALIDATION TESTING

Following completion of the developmental testing, the objective quality control procedures were validated by applying them to CM messages with known data errors resulting from forced transposition of numbers. The procedures were further validated by applying them to one set of CM messages produced for actual operational use at Fort Sill by the Meteorological Section of the 75th Field Artillery Group and to a second

[10] "The Upper-Air Verification Program," 1970, Data Verification Section, National Weather Records Center, work paper compiled by the Upper-Air Unit (RAVU) under the direction of Wilson R. Tschiffely, Jr.

set of CM messages produced under simulated field conditions at White Sands Missile Range by the Atmospheric Sciences Laboratory.

Detection of Transposition Errors

The most frequent and easily introduced error arising from human handling of CM messages is the simple transposition of digits. The ability of the objective quality control procedures to detect such errors was tested by taking CM messages known to be error free and simply forcing transposition of digits in successive locations within individual lines throughout each message, allowing only one transposition to exist at any one time in the otherwise correct message.

As coded for transmission and entry into the TACFIRE system, each line of the CM message contains 14 significant digits of meteorological data. In a full-length message of 27 lines, with 13 possible transpositions in each line, a maximum of 351 separate errors can be induced. Zero-effect transpositions occurring when adjacent digits are the same reduce the total of errors induced.

Transposition Testing Data. Five CM messages of varying lengths were used to check transposition detection. One CM message was taken from each of two different editions of FM 6-15 (1970[11] and 1978[1]). The messages are identified as messages FM 6-15(1) and FM 6-15(2), respectively, and are representative of messages produced and recorded by manual methods. The other three CM messages were taken from "Documentation of Software in the OL-192 Meteorological Data Reduction Program"[4] and are identified as messages OL-192(1), OL-192(2), and OL-192(3).

The OL-192 is a programmable calculator that is ". . . used by the artillery meteorological sections to reduce the raw meteorological data. . . . Input is entered from the calculator console for real flight time computation."[4] Thus, while the CM messages from the OL-192 are produced by machine execution of a digital program, manual entry of the raw data is still involved.

[11]FM 6-15, Artillery Meteorology, Headquarters, Department of the Army, Washington, DC, 25 March 1970

[1]FM 6-15, Field Artillery Meteorology, Headquarters, Department of the Army, Washington, DC, 30 August 1978

[4]Raymond Bellucci, Steven W. Burnett, and Thomas Richter, 1979, Documentation of Software in the OL-192 Meteorological Data Reduction Program, DELCS-TR-79-1, CS&TA Laboratory, Electronics Research and Development Command

Results. Results of applying the objective quality control procedures to CM messages containing induced transposition errors are given in table 5. Each line of the table gives the results of inducing transpositions into one of the subject messages. The number of lines in the message and the total number of transpositions possible, i.e., 13 times the number of lines, are given. The number of zero-effect transpositions is given and subtracted from the total to obtain the net number of possible detectable transpositions. The transposition induced errors detected by the objective quality control procedures are given by actual number and as a percentage of the net number of transpositions. Totals of these quantities for all five messages are given in the last line of the table.

Significantly, for the 829 transpositions detected, a total of 1682 probable-error flags were raised, indicating the effectiveness of more than one procedure in most instances, e.g., a transposition in either the temperature or pressure fields often resulted in both thickness and lapse rate probable-error flags being raised.

TABLE 5. DETECTION OF TRANSPOSITION ERRORS

Message	Number of lines	Transpositions Total	Zero	Net	Detected Errors Number	Percent
FM 6-15(1)	27	351	37	314	232	73.9
FM 6-15(2)	25	325	23	302	228	75.5
OL-192(1)	10	130	13	117	91	77.8
OL-192(2)	12	156	9	147	118	80.3
OL-192(3)	17	221	22	199	160	80.4
Totals	91	1183	104	1079	829	76.8

Unanticipated Results. In preparation for the transposition testing, the five CM messages were run through the objective quality control procedures exactly as obtained from the reference sources. Messages OL-192(1) and OL-192(3) passed all tests satisfactorily, but probable-error flags were raised in testing messages OL-192(2), FM 6-15(1), and FM 6-15(2).

a. OL-192(2) Original Data

Probable-error flags for both thickness and lapse rate were raised below line 04 and for thickness only below line 05 of message OL-192(2). Examination of the message revealed temperature values of 2770 and 2681 at lines 03 and 05, respectively, while the temperature value at line 04 was given as 0409, an obvious error. Replacement by an interpolated temperature value of 2725 removed the probable-error flags. An additional probable-error flag for lapse rate below line 03 was also raised. This flag resulted from a difference in temperature

values between lines 02 and 03 of 8.6°K, a superadiabatic lapse rate of 2.15°K per 100 meters. Such an extreme temperature structure is considered unlikely to be real and may have resulted from faulty temperature values at lines 00, 01, and 02 caused by insufficient weathering of the radiosonde temperature sensing element following a baseline check made at an unusually high temperature of 312°K.

b. FM 6-15(1) Original Data

The objective procedures raised probable-error flags for thickness below both lines 06 and 07 of the original FM 6-15(1) message, indicating an error in either the temperature or the pressure at line 06. Examination of the message showed a value for pressure at line 06 of 0689 which was actually lower than the pressure at line 07. Adjustment of the line 06 value by an even 50 millibars to a value of 0739 eliminated the thickness errors. Such an error is easily attributed to human action, misreading of the Altitude-Pressure-Density Chart ML-574 by the value of a fixed pressure interval, such as 50 millibars.

c. FM 6-15(1) Original Data

Probable-error flags were raised in the FM 6-15(2) message for excessive lapse rates below both lines 07 and 08. Examination of the available data affords no ready explanation for these meteorologically unrealistic superadiabatic lapse rate conditions.

While these probable errors are of neither the magnitude nor importance of those found in the other two messages, they nevertheless serve to additionally emphasize the effectiveness of the objective procedures in detecting meteorologically inconsistent and questionable data.

Field Data Tests

The objective quality control procedures were applied to two sets of field data for additional validation.

Fort Sill Data

The Meteorological Section of the 75th Field Artillery Group at Fort Sill, Oklahoma, routinely produces CM messages in support of artillery firings at the US Army Field Artillery School. Copies of 50 CM messages were obtained from the files of the 75th Field Artillery Group Meteorological Section to be used in further validation testing of the objective quality control procedures.

Results. Only three of the 50 CM messages received from Fort Sill failed to pass all quality control checks. Two raised probable-error flags for thickness and one raised a probable-error flag for lapse rate below line 01.

Subsequent checking of the data by the 75th Field Artillery Group Meteorological Section revealed that both thickness errors were the result of numbers being improperly copied during retrieval of the data from their files. In the first case a pressure of 0941 millibars was incorrectly copied as 0841 millibars, and in the second case a pressure of 0930 was incorrectly copied as 0950.

No copying error was found in the case of the probable lapse rate error; but according to the NCO in charge of quality control in the Meteorological Section, the line 00 temperature was indeed too high, most likely resulting from premature release of the radiosonde before complete stabilization of the temperature sensing element with the ambient surface temperature.*

All three probable-error flags raised by the objective quality control procedures were thus confirmed as valid.

White Sands Missile Range Data

During the period of October through December 1974, the Atmospheric Sciences Laboratory conducted a field project designed to test a Prototype (Meteorological) Artillery Subsystem (PASS) at White Sands Missile Range.[12] Live firings of 8-in howitzers were made to obtain data under simulated operational conditions to compare different methods of handling and processing meteorological data in support of the artillery.

The data produced during project PASS includes 556 CM messages obtained under operational conditions from nine upper air sounding sections. The CM messages were manually produced from GMD-1 rawinsonde flights, coded for teletype transmission, and sent to a central collection site. At the central site, a professional meteorologist visually checked the messages for detection of major errors before acceptance and storage in digital form on computer mass storage. Major errors that were detected upon receipt were removed by editing or by retransmission from the source, similar to current TACFIRE procedures.

These 556 CM messages have now been used as a second set of test data to assess the validity of the objective quality control procedures.

Results. Only 267 of 556 CM messages passed all objective quality control tests. The remaining 289 messages caused from one to eight probable-error flags each to be raised for a total of 642, an average of

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*Personal communication from SSG Barlow, Meteorological Section, 75th Field Artillery Group, Fort Sill, Oklahoma, 19 October 1979

[12]R&D Technical Report ECOM-5589, 1976, A Description of the Artillery Meteorological Comparisons at White Sands Missile Range, October 1974 - December 1974 ("PASS" - Prototype Artillery (Meteorological) Subsystem), compiled by Kenneth M. Barnett, ASL

2.2 probable-error flags per message. Of the 642 total, 585 were for thickness errors, 52 were for lapse rate errors, four were for wind direction changes, and one was for an incorrect surface wind direction value.

A large percentage of the thickness probable-error flags was due to pressure values that were incorrectly evaluated, recorded, or coded for tansmission. Spot checks of the data show numerous instances of pressure that can be made to fit the thickness analysis almost exactly by either an increase or a decrease of 5 or 10 millibars. In other cases, obvious transpositions or substitutions have occurred, e.g., 558 being recorded when the value should have been 588.

The PASS project data set of CM messages is atypical in that the upper air sounding crews involved had not been routinely trained in the artillery procedures for preparing CM messages. This conclusion is at least partly supported by an examination of the distribution of error flags with respect to time interval of the total project. More than 40 percent of all apparent errors was made during the first one quarter of the project period and more than 66 percent of all errors was made during the first half of the period. Obviously, the experience factor improved the performance of the personnel as time went on.

However, it is also concluded that this data set is very typical of data that undergoes one or more stages of human manipulation and handling between source and destination and as such has proved to be very good data for validation of the objective quality control procedures.

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APPENDIX. QUALITY CONTROL PROCEDURES

Detailed, exact procedures for each parameter are presented in this appendix.

SURFACE PRESSURE AND TEMPERATURE

Reduce the reported line 00 (surface) pressure and temperature to sea level. Check these reduced values against allowable limits.

Adjust Temperature

Adjust temperature by standard atmosphere lapse rate of 6.5°K per 1000 meters.

TSL = TSTA + 6.5 * HTSTA/1000,

where

TSL = temperature (degrees K) at sea level;

TSTA = temperature (degrees K) at station;

HTSTA = station elevation (meters) above sea level.

Adjust Pressure

Adjust pressure by standard atmosphere pressure-height relationship.

PSL = PSTA * (TSL/TSTA) ** [9.806/(287.0*0.0065)],

where

PSL = pressure (millibars) at sea level;
PSTA = pressure (millibars) at station;
TSL = temperature (degrees K) at sea level;
TSTA = temperature (degrees K) at station;
9.806 = acceleration of gravity;
287.0 = the gas constant for dry air;
0.0065 = the lapse rate in degrees K per meter.

Check Temperature Range

Check that TSL is within the range of 205.0° to 330.0°K.

Check Pressure Range

Check that PSL is within the range of 890.0 to 1080.0 millibars.

Raise Probable-Error Flag

Raise probable-error flag if either limit is exceeded.

LINES 01-26 PRESSURE AND TEMPERATURE

Use the hypsometric formula to compute the atmospheric layer thickness equivalent to the pressures and temperatures at the bottom and top of each layer defined by the surface and zone midpoints successively. Compare the absolute difference between the computed layer thickness and the nominal thickness from table 1 (in text of report) to an equivalent 4-millibar thickness. The value of 4 millibars has been chosen as an allowable tolerance based on the contention that density errors greater than 0.4 percent are significant. Near the surface, 0.4 percent of density can be said to be roughly equivalent to 4 millibars of pressure. Raise a probable-error flag if the absolute difference is too large.

Compute Layer Thickness

$$CTHK = 29.29 * (T2 + T1)/2.0 * \mathrm{Log}_e(P1/P2),$$

where

CTHK = computed thickness (meters);

T2 = virtual temperature (degrees K) at top of layer;

T1 = virtual temperature (degrees K) at bottom of layer;

P1 = pressure (millibars) at bottom of layer;

P2 = pressure (millibars) at top of layer.

Compute 4 Millibar Thickness

$$TOL = 29.29 * T2 * \mathrm{Log}_e[P2/(P2 - 4.0)],$$

where

TOL = allowable 4-millibar thickness (meters);

T2 = temperature (degrees K) at top of layer;

P2 = pressure (millibars) at top of the layer.

Compare

Test to see if absolute value of the difference between computed thickness (CTHK) and nominal thickness from table 1 is greater than TOL. If so, raise a probable-error flag.

TEMPERATURE - VERTICAL STRUCTURE

Compute the lapse rate for each layer in turn, starting with the layer from the surface (line 00) to 100 meters (line 01), the midpoint of computer zone 01. Raise a probable-error flag if this first layer lapse rate equals or exceeds 3.5°K per 100 meters.

Raise a probable-error flag if any other layer is found to have a lapse rate equal to or exceeding 1.2°K per 100 meters, unless such a condition exists continuously from the surface to the layer in question.

Compute Lapse Rate

$$TLR = [(T1 - T2)/ZTHK] * 100,$$

where

TLR = lapse rate (degrees K per 100 meters);

T1 = temperature (degrees K) at bottom of layer;

T2 = temperature (degrees K) at top of layer;

ZTHK = nominal thickness (meters) of the layer.

Test Lapse Rate from Surface

If T1 is surface temperature and TLR is equal to or exceeds 3.5°K per 100 meters, raise a probable-error flag.

Test Lapse Rate above 100 Meters

When T1 is the temperature from other than line 0, if TLR is equal to or greater than 1.2°K per 100 meters, and this condition does not exist continuously from the surface to the level of T1, raise a probable-error flag.

SURFACE AND WIND SPEED

Test wind speed values against limits.

Test Speed

If line 00 wind speed is less than 0 or greater than 60 knots, raise a probable-error flag.

LINES 01-26 WIND SPEED

Compute the absolute difference in wind speed between line (I) and line (I-1) for values of I from 01 to 26 in turn. If the speed difference is

less than 29 knots, accept the line (I) speed value, or if the speed difference exceeds 95 knots, raise a probable-error flag. If the speed difference is within the range of 29 to 95 knots, compute the allowable speed change (X) from the function

X = 20. + 5.95 * SQRT(Y),

where Y is the wind speed at the lower of the two lines. If the actual difference exceeds the computed allowable difference, raise a probable-error flag; otherwise, accept the speed value at line (I) and proceed to the next line.

Find Speed Difference

For each line (I) from I = 01 to I = 26, compute

DSPD(I) = ABS[SPD(I) - SPD(I - 1)].

Test Against Limits

If DSPD(I) is less than 29 knots, accept wind speed line (I); go on to the next line.

If DSPD(I) is greater than 95 knots, raise a probable-error flag.

If DSPD(I) is within the range of 29 to 95 knots, test against speed difference function.

Speed Difference Function

Compute allowable speed difference from speed at line (I-1):

ASPD(I) = 20. + 5.95 * SQRT[SPD(I-1)].

If DSPD(I) exceeds ASPD(I), raise a probable-error flag; otherwise, accept the speed value at line (I) and continue to next line.

SURFACE WIND DIRECTION

If Line 00 wind direction is less than 0, or greater than 640 tens of mils, raise a probable-error flag. Also, if line 00 windspeed is 0 and line 00 wind direction is not 0, raise a probable-error flag.

LINES 01-26 WIND DIRECTION

If the wind speed at line (I) is 0 and the wind direction is not 0, raise a probable-error flag; otherwise, proceed to test for an acceptable direction value as follows:

Find the smaller of the two wind speeds at lines (I) and (I-1). If this value is less than 25 knots, consider the wind direction at line

(I) to be correct and continue to the next line. If both wind speeds are 25 knots or greater, compute the maximum allowable wind direction difference as a function of the smaller of the two wind speeds by using the appropriate expression for the line under consideration.

If the actual direction difference between lines (I) and (I-1) exceeds the computed allowable direction difference, raise a probable-error flag; otherwise, go on to the next line.

Find Minimum Wind

For each line (I) from I = 01 to I = 26, compute

SPDMIN = MIN[SPD(I), SPD (I-1)].

Test Lower Limit

If SPDMIN is less than 25 knots, repeat previous step for next line; otherwise, go to next step.

Find Direction Difference

Compute

DDIR(I) = ABS[DIR(I)-DIR(I-1)].

If DDIR(I) is greater than 320 tens of mils (change in direction through north),

DDIR(I) = 640. - DDIR(I).

Allowable Difference, Lines 01-20

Compute

ADIR(I) = 108.0 - 0.95 * SPDMIN;

or if SPDMIN is greater than 76 knots,

ADIR(I) = 36.0 tens of mils.

Allowable Difference, Lines 21-26

Compute

ADIR(I) = 143.0 - 0.95 * SPDMIN;

or if SPDMIN is greater than 76 knots,

ADIR(I) = 71.0 tens of mils.

Test Wind Direction Change

If DDIR(I) is greater than ADIR(I), raise a probable-error flag. Otherwise, accept the wind direction at line (I) and continue to next line of message.

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